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Wind Drag on Burley Tobacco Plants

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ABSTRACT

DRAG coefficient and center of resistance to wind forces were determined for four varieties of burley tobacco at three stages of growth and using wind velocities ranging from about 3 to 17 m/s. Drag coefficients determined ranged from about 0.024 at the highest velocity to about 0.081 at the lowest velocity. Stage of growth and wind velocity had significant effects on drag coefficient. Variety did not have a significant effect on drag coefficient. Mean center of resistance varied from 42.3 percent of the distance from bottom leaf to top leaf at the early stage of growth to 71.2 percent at harvest stage. Center of resistance was significantly affected by variety, stage of growth, and wind velocity.

INTRODUCTION

The combination of heavy rain and strong winds often results in burley tobacco plants being blown over to some angle from the vertical, where they remain. If the plants are still growing, the top of each plant then turns up vertically and continues to grow in that configuration. The crooked or lodged plants are difficult to harvest by hand methods and are virtually impossible to harvest by machine. Plant breeders and farmers believe that some varieties are more resistant to lodging than others; however, no attempt has been made to determine the resistance of burley varieties to wind or to genetically select a variety that is more wind resistant.

Lodging of corn in the prairie states proved to be so much of a problem that corn breeders in Missouri (Agricultural Research, USDA, Nov. 1975) have developed varieties more resistant to lodging. McKee and Aycock (1976) recently investigated the wind resistance of Maryland tobacco. They used large fans to simulate wind in the field and found considerable differences among varieties.

Collins and Legg (1976) indicate that one of the major complaints against KY 9 by burley tobacco growers is its susceptibility to lodging. They expressed concern also about lodging of KY 14, which is a very popular variety that has been released recently. Thus, the need is evident for breeding better resistance to wind loads into the various burley varieties, particularly, those that have been observed to be susceptible to lodging. Before this can be accomplished, information is needed to define the strength of burley tobacco plants relative to wind load.

The ability of a tobacco plant to withstand wind is affected by its anchor in the soil and the size and shape of the above-ground portion of the plant. When a burley tobacco plant is blown over or lodged, it is not due to stalk failure, which occurs in many other crops, but to a failure of the soil to hold the root system securely. The burley stalk is quite strong and rigid, permitting it to support the many large leaves which are desirable for high quality burley. The large bulky plant provides a sizable target for wind to act against, thus producing considerable loads on the root system. When soil moisture increases to levels exceeding field capacity, resistance to lodging is severely reduced.

The drag force (F_D) exerted on an object by wind can be expressed by the following relationship:

$$F_D = \frac{C_D A \rho V^2}{2} \qquad [1]$$

where,

C_D = the drag coefficient for the object
A = the projected area of the object
p = the mass density of the air
V = the velocity of the air

If the drag coefficient and projected area of a plant are known, then the force exerted on the plant by a wind of known speed can be determined. Then, by testing plants in the field under certain soil moisture conditions, one can predict the wind speed which would cause lodging of the plants. However, it is necessary to know the effective center of resistance of the plant in order to apply an equivalent force as a concentrated load which simulates a wind load. An investigation was initiated to obtain this information, and the research reported here had the following specific objectives:

1 To determine forces exerted by wind on tobacco plants as a function of wind speed, variety, and stage of growth.
2 To determine the drag coefficient of burley tobacco plants.
3 To locate the center of resistance to wind of burley plants.

EXPERIMENTAL PROCEDURE

The projected area of a tobacco plant is somewhat difficult to determine and also changes drastically as high velocity air is applied to it. Therefore, we chose to use the surface area of the leaves as the characteristic area and, thus, consider the plant to be a group of thin plates oriented parallel to air flow. Leaf area is less variable and

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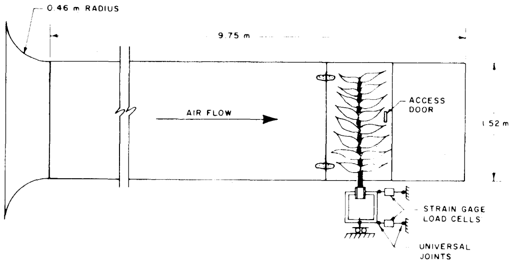

FIG. 1 A diagram of the wind tunnel and plant holding apparatus.

also easier to obtain than projected area. As air velocity is increased and the leaves become aligned more with direction of air flow, the more nearly the plant fits the model. Seginer and Rosenzweig (1971) used leaf area in determining drag coefficients for corn plants. Equation [1] is still applicable in this case; however, A is no longer projected area but the total area of all leaves on the plant. To account for the total drag force on both sides of the leaves, equation [1] is multiplied by two to yield the following relationship.

$$F_D = C_D A \rho V^2 \quad \text{[2]}$$

Four varieties of tobacco were grown in randomized plots under normal cultural practices. The varieties chosen were: (a) KY 9, a variety thought to be somewhat susceptible to blow-over; (b) KY 10, which we thought might be somewhat resistant to blow-over since its stalk is larger than some other varieties, thus it might have a larger root system; (c) KY 14, which is relatively new and quite popular due to several desirable characteristics, but suspected by some producers to be low in resistance to blow-over; and, (d) KY 41A, which has leaves that tend to droop more and could possibly reveal a difference that would aid in breeding for wind-resistant varieties. Twelve plants from each variety were tested at each of three growth stages; approximately 1 m tall, at topping stage, and at harvest stage, for a total of 144 plants.

A wind tunnel was constructed having a cross-section 0.91 m wide by 1.52 m high and a length of 9.75 m. A diagram of the wind tunnel and plant holding apparatus is shown in Fig. 1. The entrance to the wind tunnel had a curved surface with a radius of 0.46 m. This entrance was located within a large plenum chamber and air was supplied to the plenum. Air velocity in the tunnel could be varied to a maximum of about 17.2 m/s (38.5 mph). An access door in the side of the tunnel and a section of removable floor (with a slot for the stalk) were provided near the outlet to allow the plants to be positioned in the tunnel. A holding device positioned below the floor of the tunnel was instrumented with two strain-gage load cells. They were spaced 0.254 m apart vertically and oriented parallel to the direction of the air flow to measure the forces exerted on the plant. A digital strain indicator was used to read the output from the load cells. The holding device was supported on ball bearing rollers to transfer the entire horizontal thrust to the load cells.

The plants were extracted from the ground with a shovel, while keeping the root system essentially intact. The soil and roots of each plant were placed in a large container for transporting to the laboratory and watered to prevent wilting of the plant prior to testing. Leaf area of each plant was determined by measuring length and width of each leaf and multiplying their product by the constant 0.6345 as determined by Suggs et al. (1960) for bright leaf tobacco and verified for burley tobacco by Newcom (1963). Just prior to testing, the root system and associated soil were removed and the lower end of the stalk were clamped in the holding device to orient the plant in an upright position in the wind tunnel.

Each plant was subjected to eight levels of air velocity, approximately 3.1, 4.5, 6.3, 8.0, 10.3, 13.0, 15.6, and 17.2 m/s (7, 10, 14, 18, 23, 29, 35, and 38.5 mph). Forces were measured both prior to each test with no air flow and during the test with the desired air velocity. Air velocity was determined using both vane and hot wire type anemometers at a location upstream from the plant at the horizontal center of the tunnel and at the vertical quarter points. The six readings were then averaged for a mean velocity. The readings varied less than 5 percent from the mean for the locations, which indicated that air distribution was relatively uniform over the cross-section of the tunnel.

Values for drag coefficient (C_D) were calculated from equation [2] using the drag force as determined by the load cells, the measured leaf area, and the air velocity applied during a particular test. Drag force was determined by the net difference in force exerted on the two load cells.

Center of resistance (the point where all the wind forces can be considered to act) for each plant was calculated as a distance above the bottom leaf. This distance was expressed as a percent of the total distance between the bottom and top leaves on that plant. Because the model considers only the leaves as providing a drag force, the portion of stalk below the bottom leaf was not considered in locating the center of resistance. The length of this portion of stalk without leaves may vary considerably. Values for center of resistance were calculated from the forces measured by the load cells and the geometry of the apparatus.

The data were analyzed by analyses of variance to determine the effects of the three variables on drag coefficient and center of resistance. Values for drag force and drag coefficient were plotted against wind velocity. Duncan's New Multiple Range Test was used to determine significant differences between means.

RESULTS AND DISCUSSION

Only data from the six velocities ranging from about 4.5 to 15.6 m/s (10 to 35 mph) were used in the analyses of variance for both drag coefficient and center of resistance. The first velocity was omitted from the analyses because initial settling or adjusting of the plant in the holding device appeared to affect the first reading more than subsequent ones. At the highest velocity, some leaves were blown off the stalk, thus reducing the leaf area and changing the drag forces.

Mean drag coefficient for all four varieties varied from 0.081 at 3.1 m/s (7 mph) to 0.024 at 17.2 m/s (38.5 mph). The analysis of variance did not indicate a significant effect of variety on drag coefficient. However, stage of growth and wind velocity did have significant effects at the 1 percent level. The interactions of velocity with stage of growth and variety with stage of growth were also significant. Drag coefficient C_D as a function of wind velocity and stage of growth is shown in Fig. 2.

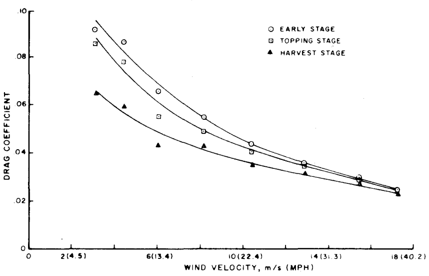

FIG. 2 Drag coefficient as related to wind velocity and stage of growth for four varieties of burley tobacco.

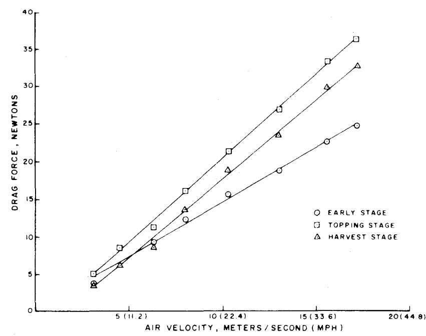

FIG. 3 The relationship between velocity and drag force exerted on burley tobacco plants at three stages of growth.

All eight velocity levels are shown in Fig. 2 to demonstrate that the drag coefficient at the highest and lowest velocities showed the same trends as it did at intermediate velocities. Greater variability in drag coefficient occurred at the lower velocities, i.e., below 8.0 m/s (18 mph). This variability may be due, in part, to changes in orientation of the leaves at lower velocities. At the higher velocities all of the leaves became aligned with the air flow and more nearly fit out model assumption of flat plates parallel to the flow. One or two large leaves oriented perpendicular to the air flow can substantially affect the drag force.

Drag force exerted on the plants is shown in Fig. 3 as related to air velocity for the three stages of growth. Data for all four varieties were combined in Fig. 3 since our analyses showed that variety did not significantly affect wind drag.

Center of resistance was significantly affected by wind velocity, growth stage, variety, and the interactions of wind velocity with growth stage and variety with growth stage.

The fact that center of resistance was significantly affected by variety, while drag coefficient was not, may be explained by the difference in leaf configuration and angle of leaf attachment among burley varieties. Variety KY 41A has leaves which tend to droop down; thus, lowering their effective point of resistance, while the other test varieties have leaves which are more erect, causing a higher effective point of resistance. Mean drag coefficient and center of resistance, as affected by variety, stage of growth, and wind velocity, are shown in Table 1. Results of Duncan's New Multiple Range Test are included in this table.

There was no significant difference between center of resistance of KY 9 and KY 10. Yet, KY 9 is believed to be susceptible to lodging, while KY 10 is believed to be one of the more resistant varieties to lodging. Neither center of resistance nor drag coefficient indicated any reason for a difference in susceptibility to wind lodging for the varieties KY 9 and KY 10. Any difference in susceptibility between these two varieties must be caused by other factors such as root weight, stalk size, etc.

Mean center of resistance varied from 42.3 percent of the distance from bottom leaf to top leaf at the early stage of growth to 71.2 percent at harvest stage. This would be expected since the upper leaves become much larger as the plant matures, causing more resistance in the upper portion of the plant. After a plant is topped (small upper leaves and flower removed), the remaining upper leaves substantially increae in area.

CONCLUSIONS

The following conclusions were drawn from the study:

1 For drag coefficient determinations, the leaves of a burley tobacco plant can be considered as a group of flat plates oriented parallel to the air flow and the surface area of its leaves is the area used in the wind drag force equation.

2 Drag coefficient for burley plants is significantly affected by stage of growth and wind velocity in the range of 3 to 17 m/s (7 to 38 mph).

3 Center of resistance to wind force of burley plants is affected by stage of growth, wind velocity, and variety.

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TABLE 1. DRAG COEFFICIENT AND MEAN CENTER OF RESISTANCE AS AFFECTED BY VARIETY, STAGE OF GROWTH, AND WIND VELOCITY

Variety		Drag coefficient	Mean center of resistance (% height above bottom leaf)
KY 9		0.046 a	60.5 a
KY 10		0.046 a	61.9 a
KY 14		0.047 a	57.6 ab
KY 41-A		0.048 a	53.1 b
Stage of Growth			
Approximately one meter tall		0.053	42.3
Topping stage		0.048	61.3
Harvest stage		0.040	71.2
Wind velocity m/s (mph)			
4.5	(10)	0.074	62.1 ab
6.3	(14)	0.054	63.5 a
8.0	(18)	0.049	56.0 b
10.3	(23)	0.039	55.5 b
13.0	(29)	0.034	55.6 b
15.6	(35)	0.029	57.0 b

Note: Any means having different letters or no letters beside them are significantly different by Duncan's New Multiple Range Test (percent level).